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Relation between Diatom Quantity, Temperature and Chlorinity in the Neighbouring Sea near the South Coast of Honshu, Japan

FUKUZO UYENO

Introduction

The principal factors controlling productivity of diatoms have been discussed by many investigators since olden times. The production is first of all dependent upon radiant energy; it requires also the presence of inorganic nutrient substances, like nitrates, phosphates, iron, and so forth, in solution in the water; and it is dependent upon physical or biological factors which operate directly or indirectly upon the availability of these dissolved substances (SVERDRUP, JOHNSON and FLEMING, 1942).

On the relation between physical characteristics and chemical components in water masses, reports have been made by many investigators, especially RICHARD and REDFIELD (1955), KAWAMOTO (1955-57), KITAMURA (1955), OKUBO (1957), has found the distinctive correlation between oxygen content and sigma t, in order to use the oxygen content for the distinction of water masses. The distribution of diatoms is also used for the identification of water masses. The quantity of diatoms may be expressed as a function of temperature and chlorinity in Osaka Bay (UYENO, 1957-b), and also it has an intimate relation to the current velocity determined by dynamical computations in the sea south of Shionomisaki (UYENO, 1957-a).

From these facts, it may be suggested that a relationship exists between diatom quantity and water masses which is shown in horizontal *T-Cl* diagram —— *hydroclimograph* ——, and moreover the characteristic of limiting factors of diatom production corresponds with the variation of temperature and chlorinity to some extent, if it is limited to the surface. In this paper the author treats of the problem of diatom quantity in the surface of Osaka Bay, the Kii Channel and the sea south of Honshu, as shown by the hydroclimograph.

Methods

The data were gathered from three series of observations conducted by Kobe Marine Observatory —— 22 observations in Osaka Bay from January, 1954 to November, 1955; 5 observations in the Kii Channel from May to December, 1953; 8 observations in the sea south of Honshu from March, 1955 to November, 1956. The total number of samples collected was 649,——253 in Osaka Bay, 69 in the Kii Channel and 327 in the sea south of Honshu.

The determination of diatom quantity was made by the following method. A sample

of surface water[1] was collected in a canvas bucket and fixed by formalin. It was condensed to about 10 cc by decanting. The 10 cc water was centrifuged for 20 minutes by 2500 rpm, and the concentrated diatoms were counted. The number of cells was given for 1 litre of sea water on a logarithmic number.

Diatom-temperature-chlorinity relationship

The diatom quantities of all samples were plotted on hydroclimograph (Fig. 1). Some data were omitted, as they were so complicated at the portion of chlorinity of about

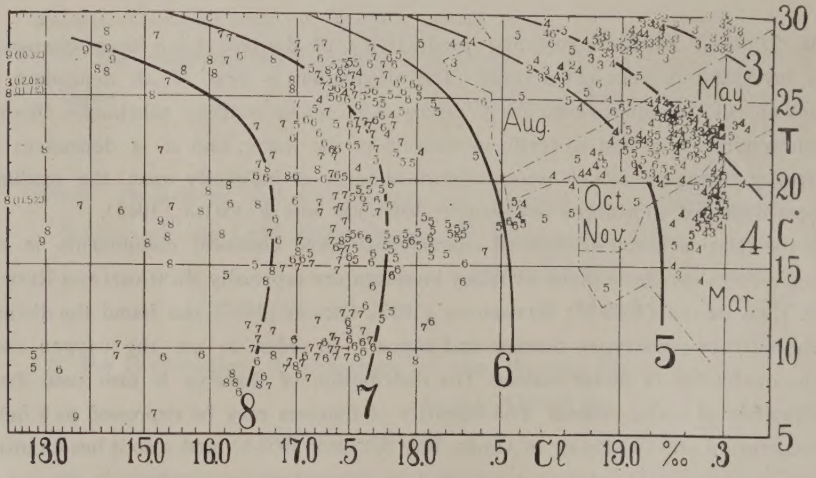

Fig 1. Diatom quantities on longrithms of cell number per 10 liter seawater on hydroclimograph in the neibouring sea of south coast of Honshu. The distributions during the months when the observations were conducted in the sea south of Honshu is shown by chain lines.

19.0‰. It is evident from Fig. 1 that, for the production of diatoms, the lowering in chlorinity is effective in the portion where the temperature is less than about 25°C and the rising in temperature is restrictive in the portion where the temperature is more than about 25°C. Moreover, it is noteworthy that the rise of temperature is rather restrictive in haline water, while the lowering of chlorinity is effective in neritic water. These facts alone do not serve for us draw a conclusion that temperature and chlorinity *themselves* may become limiting factors in diatom production. However, we may say at least that the diatom quantity depends upon the compound characteristic of temperature and chlorinity, that is, temperature and chlorinity *in situ* generally represent the limiting factors indirectly. RILEY and von ARX (1949) assumed that the processes of increase and decrease of the phytoplankton population are *accurately* expressed by a simple equation

$$\frac{dP}{dt} = P(P_h - R - G)$$

1) 100cc in Osaka Bay and the Kii Channel, 500cc in the sea south of Honshu.

in which $\frac{dP}{dt}$, the change in the population during an unit time, is equall to the initial population P times the sum of the coefficients of the physiological processes involved, namely photosynthesis P_h, phytoplankton respiration R and grazing G. It must be questioned that the formula does not involve the factors having to do with Cl distribution.

The fluctuation of quantities is rather larger in the portion of lower chlorinity than of higher, and also it depends on the composition of diatoms. In the sea south of Honshu the variation in composition is remarkably slight from coast to offing (UYENO, 1957-a); while in Osaka Bay, it follows generally the distribution of chlorinity, but the time lag between quantity and environment gives some effects on it, when changes become both rapid and great (UYENO, 1957-b). In the neritic zone, such as Osaka Bay, therefore, it is difficult to obtain satisfactory results from total cell numbers, and investigations must be made separately with regard to each species.

Horizontal gradient and anomalies in the sea south of Honshu

In the sea south of Honshu, the distributions of total cell numbers represent the tendencies for every species generally, because the variety of composition is very small from coast to offing except in winter (UYENO, 1957-a). It is possible, therefore, to discuss the relationship between the water mass and the total cell numbers, if the area is restricted to the sea south of Honshu. The distributions during the months when the observations were conducted are shown in Fig. 1 by chain lines. It is evident in Fig. 1 that the data are distributed over a very broad area in August but over a narrow area in March. The observed sea area is almost the same through out the observations, as

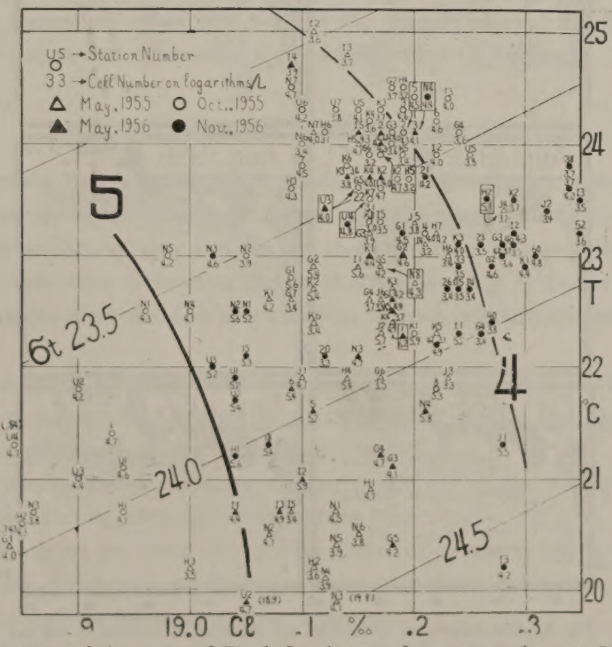

Fig. 2. Detail of the portion of Fig. 1. Distributions of stations are shown in Fig. 3.

shown in Fig. 3. If the compound characteristic of temperature and chlorinity represents the limiting factors as mentioned above, the horizontal gradient of the environmental factors is steep in summer, and gradual in winter. The large difference, in geographical distribution of each species in winter, may be due to the weak gradient. The small differences in characteristics of the reaction to the changes of environment in every species gives rise to a large difference in distribution. Accordingly, it is very important for the identification of water masses by the use of the data on diatoms, that is, of the fact that the seasonal variation in the range and gradient of temperature and chlorinity has a large effect on the geographical distribution of diatoms. In case several identifications are made using the same species of diatoms in the same region, the same species of diatoms does not always indicate the same water masses, if the seasons of their collections are different.

Detail distributions of the diatom quantities on the occasions of each of the four observations conducted in May, October and November are shown in Fig. 2, with the station num-

Fig. 3. Distributions of anonmalies and character of currents in the sea south of Honshu.

bers in each observation. Mean curves are drawn approximately on the basis of Fig. 1. Large anomalies have been picked up and the signs of positive or negative are plotted in the geographical charts, with the character of currents shown by lines with arrows (Fig.3). Similarily, the anomalies are also shown in Fig. 3 in connection with another four observations conducted in August and March.

Positive anomalies are limited in the region along the northern periphery of the Kuroshio. In this region, there is a horizontal convergence at the surface along the front of the Kuroshio, as pointed out by UDA (1938) and UYENO (1957-c). The positive anomalies indicate the results of concentration by the convergent surface flow. Accordingly, in this case, the observed quantity is the sum of the concentration and the quantity as restricted by the limiting factors.

Negative anomalies are found in the cold water region and in the south offing. In the case of the cold water region, the effect of poorly populated water in lower layers may appear in the surface due to upwelling. Therefore, in the case where the cold water region was not found as in May and Aug., 1956, or in the case where the cold water region began to appear as in Nov., 1956, no negative anomalies are observed in the offing of Enshunada. The vertical movements of water relative to the diatom distribution in the cold water region have already been treated by UYENO (1957-c), and details are omitted here. With respect to the negative anomalies which are found in the south offing, the author at present has no definite information as to its cause.

Acknowledgements

The author is indebted to Dr. Y. Matsudaira and Dr. K. Hishida who have read and made valuable suggestions concerning parts of the manuscript, and to Mr. S. Moriyasu who has made suggestions concerning the treatment of T-Cl diagram.

Conclusion and Summary

1. Diatom quantity has generally a characteristic related to the variations of temperature and chlorinity in the surface of the sea near the south coast of Honshu. Accordingly, it may be deduced that a compound characteristic of temperature and chlorinity acts as a representative of limiting factors in substance, if it is limited to the surface. However, it needs more detailed investigations on each separate species in the neritic zone.
2. Horizontal gradient of temperature and chlorinity —— limiting factors, indirectly —— is steep in summer and gradual in winter. Because of this fact, there appears in winter a wide difference in distribution of all species.
3. Positive anomalies appear along the northern periphery of the Kuroshio. It is due to the concentration by the convergent surface flow.
4. Negative anomalies are found in the cold water region and in the south offing. In the former case, it depends upon the upwelling; as for the latter case, the author at present has no definite information how it results.
5. It is concluded from the above facts that the diatom quantity near the south coast

of Honshu, is a maximum quantity limited by limiting factors which is modified by mechanical actions, such as convergence and upwelling.

References

KAWAMOTO, T.

1955–57. On the distribution of the dissolved oxygen in the Pacific Ocean. I-III. (in Japanese), Umi To Sora, **32**-2, **32**-5,6, **33**-1,2.

KITAMURA, H.

1955. The study of horizontal σt-O_2 relation to water mass separation. (in Japanese), Umi To Sora, **32**-3.

OKUBO, A.

1957. Estimation of biological effects in the distribution of dissolved oxygen by use of isopycnic analysis (The distribution of dissolved oxygen in the sea east of Honshū, Japan I), Oceanog. Mag. **9**-1.

RILEY, G. A. and R. von Arx.

1949. Theoretical analysis of seasonal changes in the phytoplankton of Husan Harbor, Korea, Jour. Mar. Res., **8**-2.

SVERDRUP, H. U., M. W. JOHNSON and R. H. FLEMING.

1942. The oceans; their physics, chemistry and general biology. New York.

UDA, M.

1938. Researches on "Siome" or current rip in the seas and oceans, Geoph. Mag., **2**-4.

UYENO, F.

1957-a. On the relations between the distribution of diatoms and the Kuroshio in the sea south off Shionomisaki, (in Japanese). Umi To Sora, **33**-1,2.

1957-b. The variation of diatom communities and the schematic explanation of their increase in Osaka Bay in summer, I-III, (in Japanese), Jour. Ocean. Soc. Japan, **13**–2, 3.

1957-c. Water movements and distributions of diatoms in a vertical section of the cold water region off Enshu-nada, Japan, Mem. Kobe Mar. Obs., **12**-1.

Water Movements and Distributions of Diatoms in a Vertical Section of the Cold Water Region off Enshu-nada, Japan

FUKUZO UYENO

Introduction

In the offing of Enshu-nada there often appears a cold water region, where upwelling is observed. This phenomenon is evoking much interest among those concerned with oceanography and fisheries. Since 1954, the Kobe Marine Observatory has carried out several oceanographical observations in this region, as part of a series of observations conducted in the sea south of Honshu. Simultaneously with the observations, diatom samples have been collected from several layers within the upper 300 m along long. 137° 40′ E line in five observations in the past, namely, Aug., 1955, Mar., May, Aug. and Nov., 1956, In the present paper, the author discusses about the relationship between water movements and distributions of diatoms in a vertical section, concerning to the existence of the cold water region.

The determination of the diatom quantity has been made by the following method. A water sample —— 330-500cc —— is collected from a Nansen bottle and fixed by formalin. It is concentrated by decanting and centrifuging. The number of cells is given for 1 liter of sea water. Samples have been collected generally from six layers, i. e. at 0, 50, 100, 150, 200 and 300m.

General features of the sea condition and the distribution of diatoms

The cold water region was found clearly in Aug., 1955, Mar. and Nov., 1956, and disapeared in May and Aug., 1956. The changes of the main axis of the Kuroshio are shown in Fig. 1, together with the location of the cold water region.

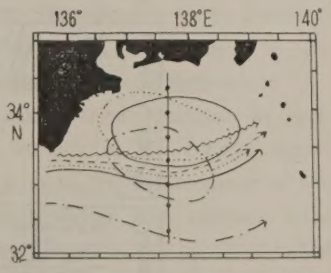

Fig. 1. Observing section, and the changes of the axis of the Kuroshio and the location of the cold water region. Chain line: Aug., 1955. Dotted: Mar., 1956; Waved: May, 1956. Broken: Aug., 1956; Solid Nov., 1956.

The thermocline appears at a depth of about 25m in summer and about 150m in winter on the north of the upper layers of the thermocline, there is an isothermal, less haline; and a diatom rich zone throughout the year. In the lower, both temperature and chlorinity are stratified, and the maximum chlorinity appears just below the thermocline. The thermocline goes down to a depth of 300 to 400m on the south of the Kuroshio. The portion of declined isotherms, in the vertical section, corresponds to the maximum current zone of the Kuroshio. The warm core is most

haline and is found in the upper 100 m adjacent to southern periphery of the Kuroshio. This is considered to be originated to the southern waters transported by the Kuroshio,

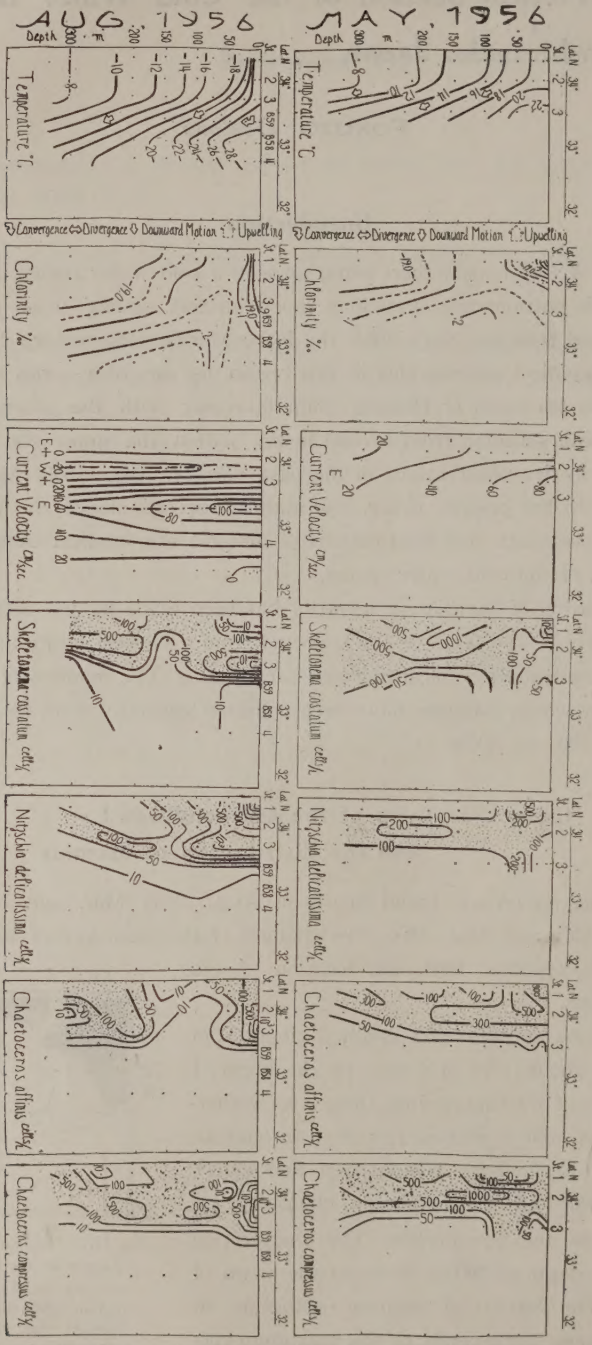

Fig. 2. Distributions of temperature, chlorinity, current velocity and diatoms on Aug. and May, 1956, when the cold water region is not observed.

though its location is deviated to the right of the maximum current zone (ICHIYE, 1955). Diatom quantities in the core are very scanty except in winter, and few tropical species appear in summer. The horizontal gradient of limiting factors is steep in summer and gradual in winter, and the variety of the composition is small from coast to offshore in summer but large in winter (UYENO, 1957). In winter, the distributions of principal species are divided into about three groups (Kobe Marine Observatory, 1956). From among these groups *Skeletonema costatum*, *Nitszchia delicatissima*, *Chaetoceros affinis* and *Ch. compressus* have been adopted as typical of these species, the last two belong to the same group.

Features in cases where the cold water region has disappeared

Distributions of temperature, chlorinity, current velocity and diatoms in May and Aug., 1956, when the cold water region is not observed, are shown in Fig. 2. According to it, the thermocline is located at a depth of 25 to 50m in May and at a depth of 10 to 50m in Aug. The directions of isotherms and isohalines are almost horizontal in the lower layers of the thermocline on the north of the Kuroshio. The part where diatoms are densely distributed is found vertically on the north side of the declined part of the thermocline, such as the northern periphery of the Kuroshio. In May, some difference in the distribution of every species appears in the layer between the surface and the depth of 50m; and in Aug., all species are abundant at St. 3. The difference is considered to be due to the horizontal gradient of environment. At the projecting part of more haline waters, sourrounded by an isohaline of 19.2‰, there is a poor population.

Features in cases where the cold water region has been found clearly

The distributions of temperature, chlorinity, current velocity and diatoms in Aug., 1955, Mar. and Nov., 1956, when the cold water region was found clearly, are shown in Fig. 3. As compared with Fig. 3 to Fig2, great differences of features are not found to the south of the Kuroshio. To the north of the Kuroshio, isotherms and isohalines show a mountain-like shape, though they are horizontal in Fig. 2. This shape may be considered due to upwelling, and the slope is steep in winter and gradual in summer. The depth variation of thermocline is similar to the cases where the region disappeared.

The distributions of diatoms are complicated and indicates various features in each observation. Densely populated parts were found on the surface of the coastal region and the southern periphery of the cold water region in general, as was common to the four species in Aug., 1955 and Nov., 1956. Maximum quantities of each stations were found near the surface at both peripheries of the cold water region, and appeared in the subsurface layer at the central portion. The quantities were remarkably larger in Nov. than in Aug. In Mar., 1956, on the contrary, densely populated parts were found near the coast and at the southern periphery of the Kuroshio, and the distributions of quantity were characteristic in each of the four species. *Skeletonema costatum* was abundant near the coast, while *Chaetoceros affinis* and *Ch. compressus* were found mainly in the

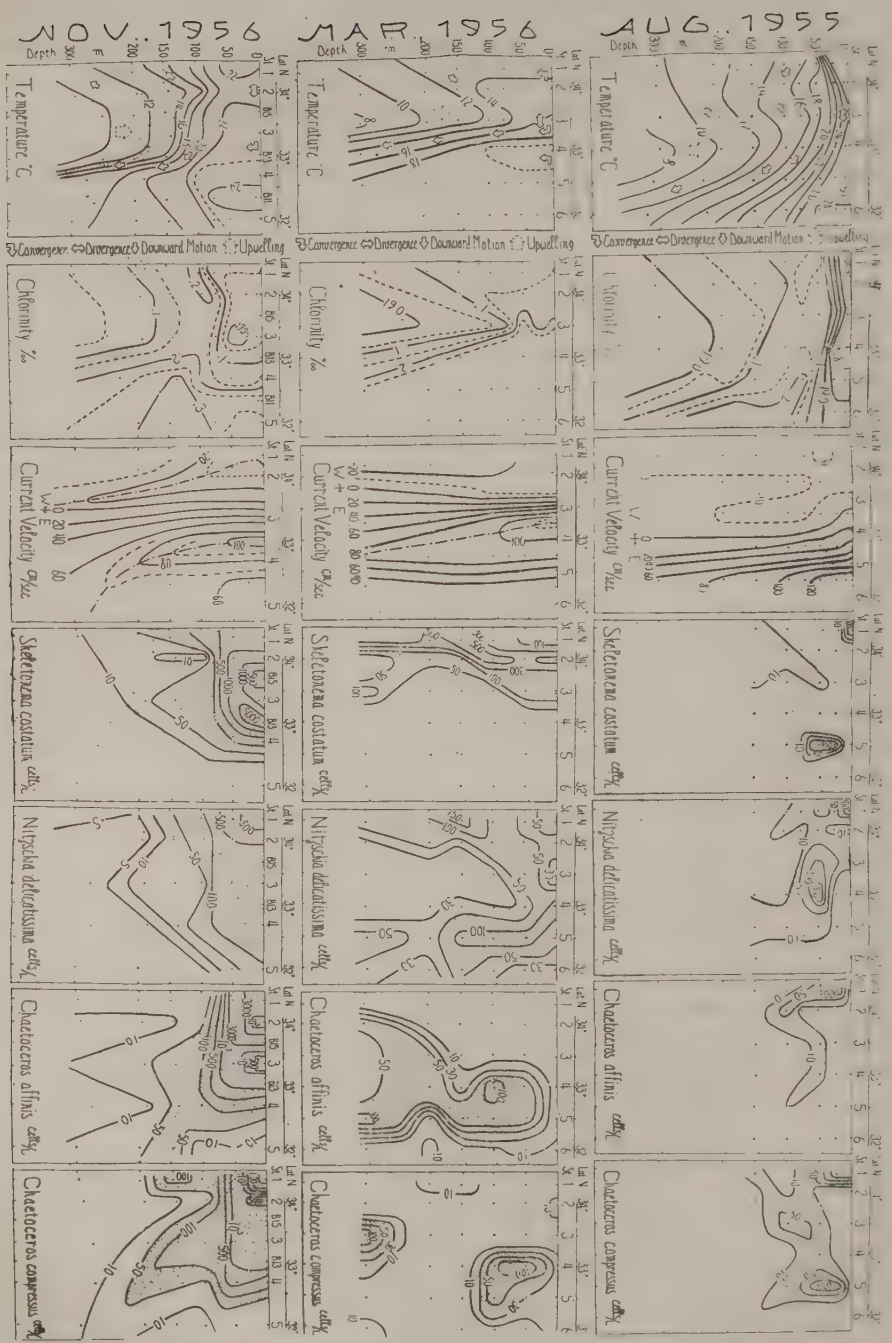

Fig. 3. Distributions of temperature, chlorinity, current velocity and diatoms on Aug., 1955, Mar. and Nov., 1956, when the cold water region was found clearly.

south of the Kuroshio. *Nitzschia delicatissima* covered both regions.

In the layers lower than the thermocline, it is noteworthy that the densely populated parts were found almost parallel to isotherms of 12° and 14° C and isohalines of 19.05 and 19.10‰ in every species throughout all observations, though there appeared a slight deviation according to the species. Therefore, the scanty region occupied a rather broader area in the case where the thermocline was located near the surface, than in the case where it was located in the deeper layer.

Discussion

Diatom production is, first of all, dependent upon radiant energy. The euphotic zone is richly fertilized in readiness for diatom growth, while, in the disphotic zone, no diatom production can take place, and the diatoms found here have been mostly sunk from the layer above. So, the determination of the compensation depth is important for the analysis of vertical distribution of diatoms.

The determination of the compensation depth in routine observations is difficult, because transparency is the only factor relative to light. Fortunately, light intenisities in various wave lengths were measured accurately by SASAKI, OSHIBA and OKAMI of the

Table 1. Transparency in meter along long. 137° 40'E line.

Station		1	2	3	4	5	6
Aug.,	1955	23	25	20	—	33	33
Mar.,	1956	21	—	—	—	30	35
May.,	1956	14	—	—			
Aug.,	1956	23	22	—	—	41	
Nov.,	1956	22	19	27	—	—	

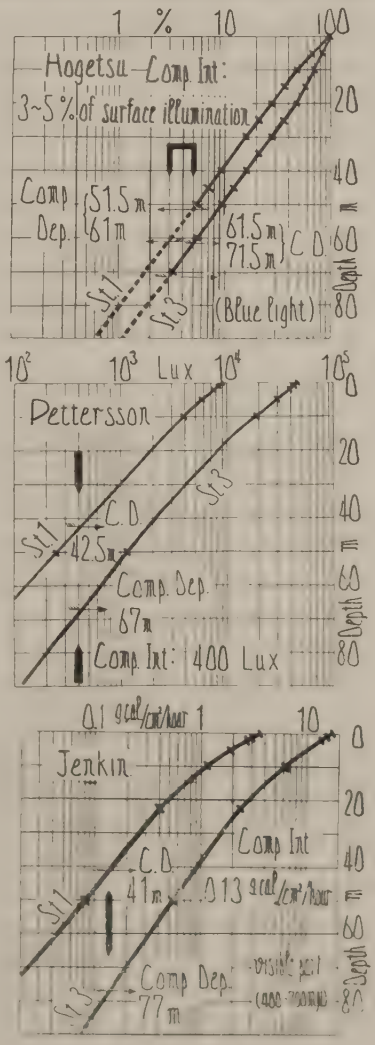

Fig. 4. Submarine illumination on Nov. 18 and 20, 1956, measured by SASAKI, OSHIBA and OKAMI and the compensation depths contained in the three reports by HOGETSU et al, 1954, PETTERSON et al. 1934, JENKIN, 1937.

St. 1 : Date: Nov. 18
Lat.: 33°40′ N. Long.: 135° 50′ E
Local time: 11.32-12.33
Sea : 1, Sky : over cast
Transparency : 18 m

St. 3 : Date: Nov. 20
Lat. : 33° 20′ N. Long. : 135° 40′ E
Local time : 11.35-12.25
Sea : 2, Sky : clear
Transparency : 36 m

Scientific Research Institute at two stations of lat. 33°40′ N, long. 136°50′ E and lat. 33°20′ N, long. 135°40′ E on Nov. 18 and 20, 1956. Moreover, OKAMI estimated the compensation depths at noon from the data contained in the three reports by PETTERSON et al (1934), JENKIN (1937) and HOGETSU et al (1954), as are shown in Fig. 4. The differences in the compensation depths obtained on the basis of the three reports are small. Transparencies which were measured in five observations are shown in Table 1. From Fig. 4 and Table 1, it may be said roughly that in the sea adjacent to the cold water region, the compensation depths exist generally at a depth between 50 and 100 m throughout the year. Therefore, diatoms increase aproximately at the isothermal layer, though the seasonal shifts of the thermocline are opposite to those of the compensation depth. Diatom production is dependent on various factors, such as temperature, nutrient substances, grazing and so forth, besides radiant energy. The data used in this paper are rather rough for analysing them, and therefore, the discussion below stated concerning the euphotic zone is limited only to the bore outline.

The diatom quantity in the surface of the sea south of Honshu is mainly dependent on the compound characteristic of temperature and chlorinity. The negative anomalies appear at the center of the cold water region, while positive ones are found at the northern periphery of the Kuroshio (UYENO, 1957). Densely populated parts, which appeared at the surface of both peripheries of the cold water region, is owing to horizontal convergent flow at the surface. And the abundant zone, which was found along the northern periphery of the Kuroshio, is also affected by the surface convergent flow along the front. At the center of the cold water region, the upwelling waters seem to reach to the surface. Then, there may be found a divergent flow in the surface at the center of the region. The fact that the diatom quantity at the surface was smaller than at the subsurface, is considered due to the effect of surface divergent flow.

In the disphotic zone there was observed a remarkable feature relating to the upwelling. A densely distributed part was found vertically in the case when the upwelling was not observed. On the contrary, when the upwelling was observed, the dense distribution was found along the isotherms of 12° and 14° C, but very scanty in the center of upwelling. From the above facts, it may be said that diatoms fall vertically in the former case, while diatoms keep away from the upwelling in the latter case. It is considered from the above that those isotherms may be in the surface of upwelling. Moreover, when the apex of the upwelling was flat, the distributions of diatoms expanded towards lower beyond the isotherms of 12° to 14° C. This case was found in Nov., 1956 (see Fig. 3). Accordingly, it may be assumed that diatoms fall vertically at the portion where the distribution of isotherms are horizontal, and they fall along the isotherms at the portion where they are declined. In the latter case, we may consider a downward movement of waters along the declined isotherms.

Water movements stated above, such as convergent flow, divergent flow, upwelling and downward motion along declined isotherms, are shown by various arrows in Figs. 2 and 3, and they are generally similar to the "cell-like motion" and "hypothesized basic circulation" which were found in the central tropical Pacific by CROMWELL and

REID, Jr. (1956). In their investigations, "cell-like motion" means water movements in the isothermal layer, and "hypothesized basic circulation" means the sinking along fronts. But they had no information about where water rises to the surface to compensate the latter motion. However, it may be deduced that "cell-like motion" is only the surface convergent flow near the front and the compensation of both motion is upwelling. The result obtained above is also found to be in accord with the formation of water mass by sinking along the σ_t surface in a region of convergence, as observed by SVERDRUP, JOHNSON and FLEMING (1942), because of the fact that the σ_t surface coincides with the parallel temperature and chlorinity surfaces.

Acknowledgements

The present writer appreciates the helpful suggestions from Mr. S. Moriyasu concerning some of the physical sea conditions. The author most gladly and gratefully acknowledges his indebtness to Dr. T. Sasaki, Mr. G. Oshiba and Mr. N. Okami for supplying me with unpublished data on submarine daylight. Especially, Mr. N. Okami was good enough to estimate the compensation depth, and Dr. Y. Matsudaira and Dr. K. Hishida to read and make valuable suggestions concerning parts of the manuscript.

Summary

1. In the case where the cold water region disappeared, the part densely populated by diatoms was found vertically at the northern periphery of the Kuroshio, both in the euphotic zone and the disphotic zone.

2. In the case where the cold water region was found clearly, densely populated parts were found at the surface of both peripheries of the cold water region, and densely distributed part in the disphotic zone was found along the isotherms of 12° and 14° C which show a mountain-like shape. There were no diatoms in the center of the upwelling.

3. At the surface of the cold water region, there is observed a divergent flow at the center and convergent flows in both peripheries.

4. Diatoms fall vertically at the portion where the isotherms run horizontal, while they fall along the isotherms at the portion where the isotherms are declined. Therefore, in the latter case, a downward movement of waters must be taken into consideration along the declined isotherms.

5. The features of water movements are generally similar to the "cell-like motion" and "hypothesized basic circulation" as observed by CROMWELL and REID, Jr (1956). However, "cell-like motion" may be considered to mean only a surface convergent flow near the front.

References

CROMWELL, T. and J. L. REID, Jr.

1956. A study of oceanic fronts, Tellus, 8-1.

HOGETSU K. and S. ICHIMURA

1954. Studies on the biological production of Lake Suwa. VI The ecological studies on the production of phytoplankton, Jap. Jour. Bot., **14**-2.

ICHIYE, T.

1955. On the variation of ocean circulation (V), Geoph. Mag., **26**-4

JENKIN, P. M.

1937. Oxygen production by the diatom *Coscinodiscus excentricus* Ehr. in relation to submarine illumination in the English Channel, Jour. Mar. Biol. Assoc., **22**-1.

KOBE MARINE OBSERVATORY

1956. Report of the oceanographic observations in the sea south of Honshu in March, 1956, (in Japanese), Oceanog. Rep., Jap. Met. Agency, **5**-2.

PETTERSON, H. H. and S. LANDBERG

1934. Submarine daylight and the photosynthesis of phytoplankton, Göteborg Vetensk. Samh. Handl., **5**, B-4-5.

SVERDRUP, H. U., M. W. JOHNSON and R. H. FLEMING

1942. The oceans; their physics, chemistry and general biology, New York.

UYENO, F.

1957. Relation between diatom quantity, temperature and chlorinity in the neighbouring sea along the south coast of Honshu, Japan, Mem. Kobe Mar. Obs., **12**-1.

On the Distribution of Phosphate in the Western North Pacific

HIROYUKI KITAMURA

Abstract

The distribution of inorganic phosphate phosphorus both on isopycnic surfaces and in vertical sections has been studied on the basis of data made available from the observation conducted in the summer of 1955, or the operation NORPAC as it is called. From this it is proved that along the isopycnic surface the characteristics in distribution are simple in the open ocean, while they are complicated in the seas adjacent to the land. On the other hand, it is made clear that the vertical distribution of phosphate on the polar front varies systematically according to the longitude.

Introduction

The distrbution of nutrient salt in the open ocean of the Pacific has so far been studied methodically only in a few cases: one survey was made by SVERDRUP (1942) on the strength of *CARNEGIE*'S data about the longitudinal vertical section in the Central Pacific. Another was by MONTGOMERY (1954) on the distribution of inorganic phosphate in its relation to that of Sigma-*t* and temperature in the Equatorial Pacific, which gives a standard for the judgement of sea condition. The operetion NORPAC in the summer of 1955 provides the data which lead to a series of researches into the distribution of inorganic phosphate to other elements in the Western North Pacific (Latitudes 20°-45°N., Longitudes 130°-180°E.). The data available are from the oceanographical observations participated in by: 1) the Central Meteorological Observatory, Tokyo (1956; 2) the Japanese Hydrographic Office (1956; 3) the Tokyo University of Fisheries (1956) and 4) the Tokai Regional Fisheries Research Laboratory (1956).

Phosphate distribution on the isopycnic surface

The Sigma-*t* surface proves to be most fitted for the horizontal transition of water, and then it is assumed that the horizontal mixing of water in turbulent flow takes place along this surface.

Let us take the temperature-chlorinity relation in the KUROSHIO for an example: the minimum chlorinity stands at Sigma-*t* 26.8, and the core of intermediate water at Sigma-*t* 27.0. The distributions of phosphate along the above two isopycnic surfaces are given below.

The phosphate concentration in the water of Sigma-*t* 26.8 surface (Fig. 1) stands at 1.5 μg-atoms L along latitude 30°N. in the region east of longitude 150°E., and it tends to increase in a slight degree northward or southward of 30°N. Though the phosphate

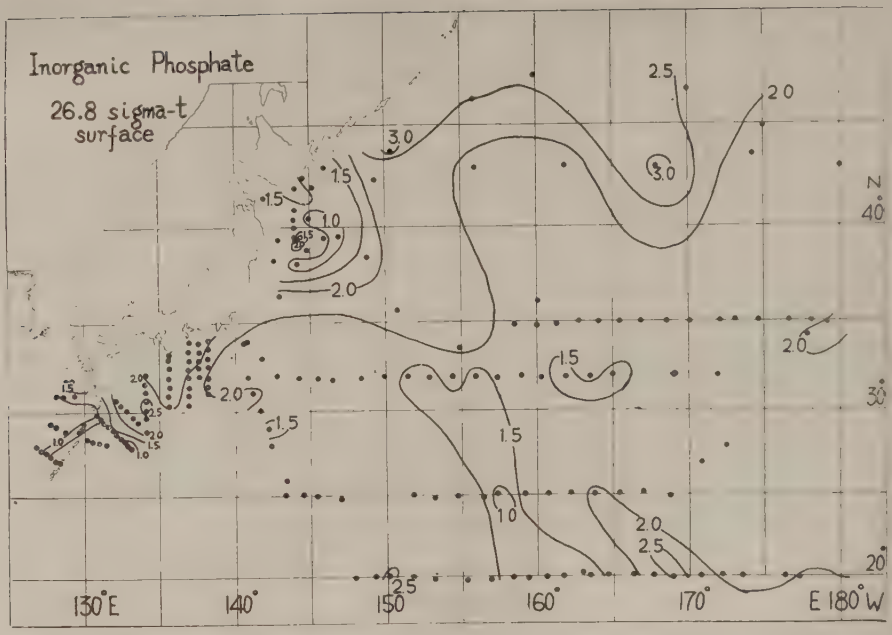

Fig. 1. Inorganic phosphate in microgram-atoms per liter on the 26.8 sigma-*t* surface. Points indicate station positions.

concentration is seen coming up to 3.0 μg-atoms/L at latitude 43°N., longitude 168°E., it is regarded as a phenomenon particular to the spot.

Varieties of distribution forms may be seen in the adjacent sea of Japan and especially in the regions north of latitude 35°N. where the KUROSHIO, the OYASHIO and another flow coming through the Tsugaru Strait mix together and the phosphate concentration varies in a marked degree from 1.0 μg-atoms/L to more than 2.0 μg-atoms/L. Here is an example of the distribution form in the seas of Kyushu and of Honshu. Though the latter was taken from the observation one month before that of the former, the discontinuous gradient of distribution may be considered to result not from the lapse of time between the two observations, but from other elements belonging to the coastal regions.

It is observed that the Sigma-*t* 26.8 surface presents itself at the depth of 150 meters at latitude 45°N. The depth increases southward, until it stands at 700 meters at latitudes 32° to 30°N. It remains at about 700 meters southward to latitude 25°N., where it tends to decrease. The depth reaches to more than 800 meters in the adjacent sea of Japan at latitude 32°N., longitude 147°E., and the surrounding area, where the sinking of the intermediate water as well as the Sigma-*t* 27.0 surface is considered to reach its maximum.

The phosphate distribution on the Sigma-*t* 27.0 surface (Fig. 2) is similar to that on the 26.8 surface along latitude 30°N., but dislocates a little westerly. Thus the distribution at 2.0-2.5 μg-atoms/L may be found over a wide area west of longitude 168°E. There is a small gradient of increase in the area north and south of this zone. In the

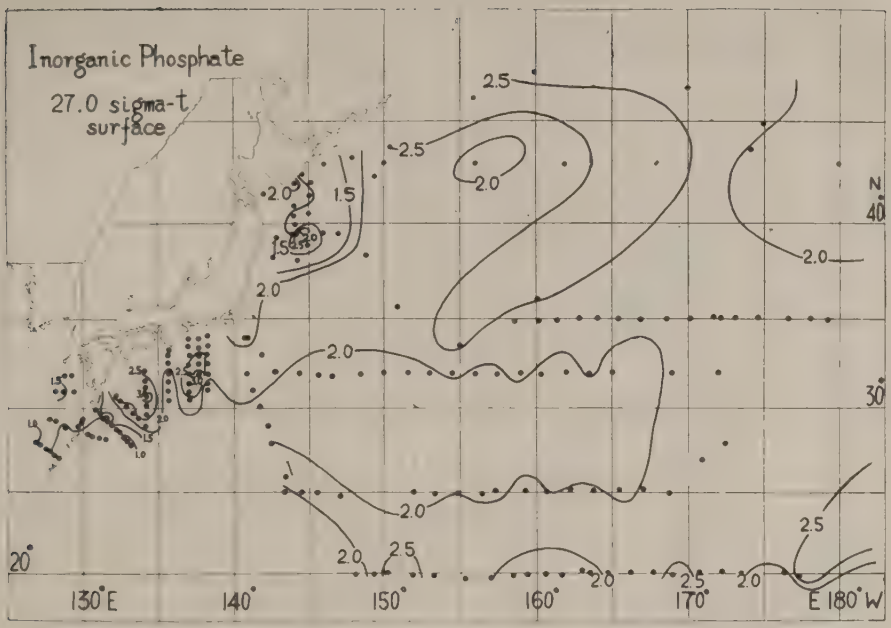

Fig. 2. Inorganic phosphate in microgram-atoms per liter on the 27.0 sigma-*t* surface. Points indicate station positions.

adjacent sea of Japan north of latitude 35°N., the tongue distribution area which is stretching from the Tsugaru Strait shows a tendency similar to that of the Sigma-*t* 26.8 and the concentration decreases generally towards the center (1.25 μg-atoms/L) from the offing (2.0 μg-atoms L) at a greater gradient as compared with cases in the open ocean. In the area south of Honshu, the phosphate concentration comes up to more than 3.0 μg-atoms L and the depth reaches to more than 900meters and presents a complicated distribution form.

Vertical longitudinal section of phosphate

Fig. 3 shows an example in the western part of the North Pacific Ocean: the distribution in the longitudinal section between latitudes 20°N. and 50°N along longitude 160°E. On the same scale, the distribution of Sigma-*t* and current velocity in that section is shown in Fig. 4. It reaches as for as 1.0 2.0 μg-atoms L in the upper layer north of latitude 40°N., while the depth comes down to 400-500 meters at 1.0 μg-atoms L from latiude 34°N. southward. From this it is evident that the changes of phosphate exist on the polar front. Now, the isopleth of 1.0 μg-atoms L runs nearly parallel with the Sigma-*t* 26.0. The polar front is located at the place where the current, running at 16.0-18.0 cm sec. easterly, reaches its maximum velocity in this section. The phosphate distribution at the depth of more than 800 meters does not form stratification but makes local and gradual increases with the depth. Such changes are also found in the under-mentioned sections.

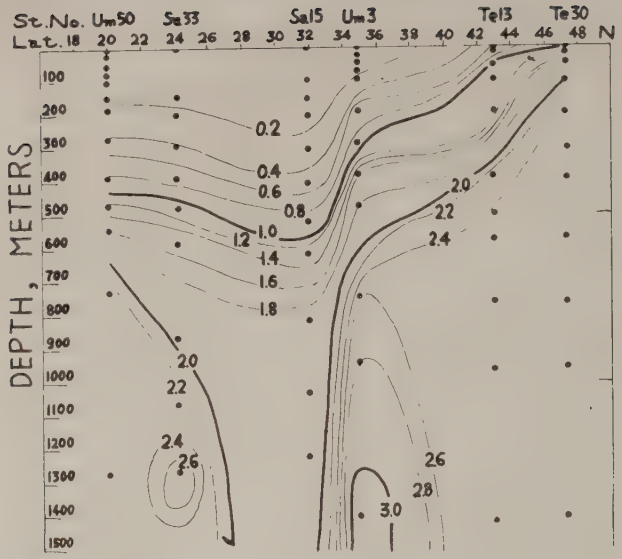

Fig. 3. Meridional section of inorganic phosphate in microgram-atoms per liter along 160°E. longitude.

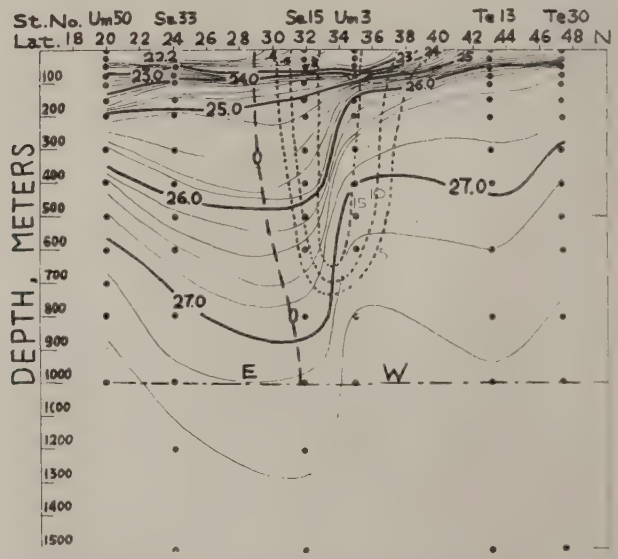

Fig. 4. Meridional section of density (σt) and the geostrophic currents along 160°E. longitude. Currents magnitude in cm/sec.
E·····East currents.

In the polar front region, the slope of isopleth in phosphate may be readily shown (Fig. 5) at longitude 170°E. and latitudes 36°-42°N.; longitude 165°E., latitudes 32°-36°N.; longitude 155°E., latitudes 36°-40°N.; and longitude 150°E., latitudes 38°-42°N. At longitude 144°E., it is situated at latitudes 38°-40°N., where the transition of intermediate water is clearly seen at the steepest slope of isopleth. From this it may be considered

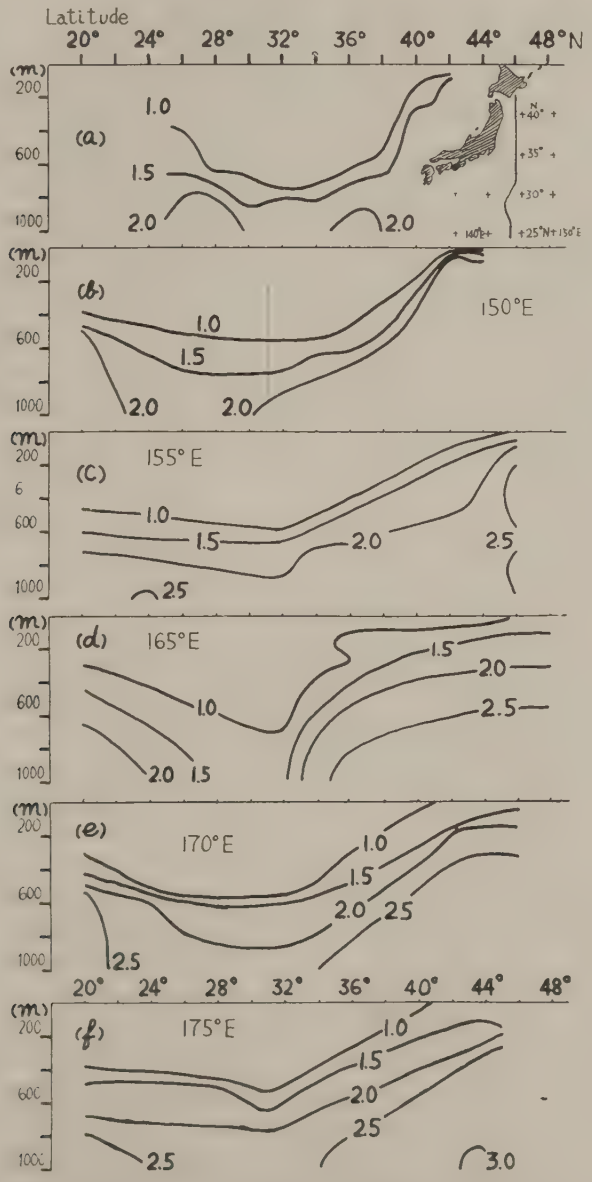

Fig. 5. Meridional section of inorganic phosphate in microgram-atoms per liter along the longitude. a) 144°E., b) 150°E., c) 155°E., d) 165°E., e) 170°E., f) 175°E.

that in the regions adjacent to Japan, the KUROSHIO and the OYASHIO mix up together to cause the sinking at a notable rate, and this tendency decreases gradually in the more easterly parts or towards the center of the ocean.

Summary

1. As the Sigma-t may be taken as potential density, it has been studied how the distribution of phosphate is on the isopycnic surface as based upon the water type of the KUSOSHIO. It is seen that the phosphate on the Sigma-t 26.8 surface is poor in the zone along latitude 30°N., and increases gradually in the regions northward and southward away from that latitude. The distribution of phosphate on the Sigma-t 27.0 surface shows a similar pattern to that on the 26.8 surface, though the poor area dislocates slightly in the one from the other. Both make up a complicated phase of distribution in the seas near Japan.

2. As for the vertical distribution in the longitudinal section, the polar front presents clearly the distribution and changes of phosphate.

Refferences

Central Meteorological Observatory, Tokyo.

1956. The results of Marine Meterological and Oceanographical Observation. No. 17

MONTGOMERY, R. B.

1954. Analysis of Hugh M. Smith Oceanographic Section from Honolulu across the Equator. J. Mar. Res., **13**(1), 67-75.

SVERDRUP, H. U. et al.

1942. The Oceans. New York: Prentic-Hall, Inc. 709-711.

The Japanese Hydrographic Office.

1956. NORPAC Oceanographic and Meteorological Data.

Tokyo University of Fisheries.

1956. Oceanographical and Meteorological Data. (NORPAC PROJECT)

Tokai Regional Fisheries Research Laboratory, Tokyo.

1956. NORPAC Data of Hydrographic Observation by the R. V. Tenyo-Maru July 18-September 8,1955.

On the Forecasting of the W-ly Monsoon in Winter

YASUJI KAWANABE

Introduction

Monsoons have been a subject of study by many since old days, nevertheless, there has unfortunately been none too copius literature dealing with their forecasting. Furthermore, the past studies had mainly depended upon the surface maps and the forecasting period was limited to within 24 hours.

After the 2nd World War, however, there has been a rapid development in upper observations in Japan, and observations in the neighbouring countries also have made remarkable progress in recent years. In view of these new developments, we have changed our basic stand point so as to base our study in monsoon forecasting on the upper maps, and a trial to extend the forecasting period as much as possible was pursued. The monsoon is occured as the result of reciprocal actions between a deepening cyclone passing through the Japan Sea and a predominant continental anticyclone. Consequently, there are two important factors to be considered in study of the subject under review, one being the cyclone which passes through the Japan Sea and the other the anticyclone located near Mongolia.

Development of cyclone around Japan.

In a word, a strong upper divergence is the condition essential for the development of a cyclone. In the case of the model in Fig. 1, the strong divergence regions are found in the lst and 3rd quarter regions of the Jet Center.

To adopt this model in realizing the cyclone development near Japan, a strong divergence in the lst quarter region gives rise to the development of a cyclone which passes through the Japan Sea, and that in the 3rd quarter region to the development of another cyclone which passes along the south coast of Japan. Of course it must be added that this is not always the case.

i) Deepening cyclone that develops along the south coast of Japan.

In the 3rd quarter region of the Jet Center, both the curvature and the wind shear terms of the vortex decrease in the downstream and complete the divergence region. This region also forms a confluence zone.

The theory of cyclone development due to confluence is explained by Prof. J. Bierkness[1] as follows.

$$V_\eta = \frac{u \dfrac{\partial u_g}{\partial x}}{2\Omega z - \dfrac{\partial u_g}{\partial \eta}} \qquad (1)$$

Here, η is directed towards the north along the surface of iso-potential temperature and x towards the east.

In the 3rd region of Fig. 1, $\dfrac{\partial u_g}{\partial x} >> 0$ and $\dfrac{\partial u_g}{\partial y} \approx \dfrac{\partial u_g}{\partial \eta} > 0$.

Then, V_η has a large value. Accordingly, the upward motion will be strong and the cyclone is apt to develop.

In general, there is no outbreak of the cold air in this region, and therefore, we can expect no sudden changes. Along the Pacific coast, however, strong E-ly and N-ly winds are apt to occur, but no continuous W-ly monsoon develops. Nevertheless as explained in the later section, this cyclone performs a preliminary action for the W-ly monsoon.

ii) Deepening cyclone over the Japan Sea area.

In this case, the cyclone passes through the 1st quarter region in Fig. 1. Therefore, it will develop owing to the remarkable divergence in this region. In general, we always have no strong trough in this region at first, but, when the cold air outbreak takes place, a remarkable trough will result. In consequence, this pattern undergoes a sudden change in many instances. Due to the rapid development of the cyclone, a strong W-ly monsoon will blow around Japan and in its neighbourhood. If the Japan Sea is situated at the 3rd region, the cyclone would, of course, develop, but then only temporary strong north winds will blow after the cyclone has passed away.

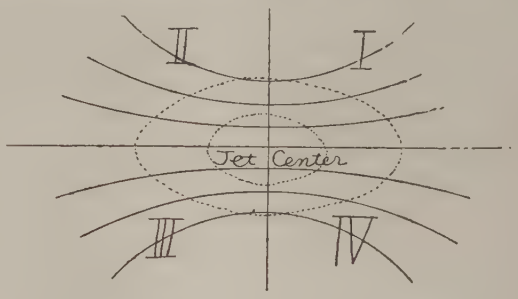

Fig 1 Thd model of Jet Center
Mark Ⅰ and Ⅲ ineicate the divergence regions and, Ⅱ and Ⅳ indicate the convergence regions.

Continental Anticyclone

For the strong monsoon, a influential Continental anticyclone is favourable, but things deepend mainly on the way of the anticyclone explosion.

For instance, when the anticyclone extends to the Japan Sea, only N-ly winds will blow in the Western Japan.[(2)]

On the other hand, when the anticyclone extends from the Loochoo Islands to the ocean far down to the south of Japan, a monsoon is apt to occur all over Japan, even though the anticyclonic pressure is weak.

The upper pattern of a W-ly monsoon has a divergence region over the Japan Sea, while in the N-ly wind pattern a convergence region is formed over the same area in many cases.

The differences between the divergence and the convergence patterns are shown in Tables 1 and 2, based on a study of the wind shear and the curvature.

i) Wind shear

For the wind shear the 500mb height difference between (Shionomisaki-Yonago) to (Wajima-Vladiostok) had been substituted. In the case a Jet center is situated over the trough near Korea or E-ern China, divergence will be strong around Japan according as the value of this term is large.

ii) Curvature

We are able to estimate the curvature effect by means of the height difference between two points nearly on the same latitude.

We have chosen Yonago and Tateno for this purpose in the present study. In general, divergence will occur when the height at Tateno is greater than that at Yonago; and convergence will take place under reverse conditions. When the absolute value is compared between the curvature and the wind shear term, the former has greater influence for divergence in many cases.

Therefore, when those two terms are opposed to each other, the latter may be ignored in comparision with the former. From the above, it is observed that, when the monsoon blows around Japan, divergence is found over the Japan Sea, in other words, surface isobars show cyclonic curving in that area. On the other hand, N-ly winds are an indication of convergence. Another characteristic of the situation is found in regard to the anticyclone.

During a monsoon is blowing, the continental anticyclone moves rapidly southward and its central pressure decreases. This fact shows the outbreak of the polar cold air and the result of the Coriolis effect upon pressure change. In spite of the falling of the anticyclone, the pressure gradient over Japan in no way affected as the center comes near to it.

We have assumed that when the value of $\frac{\partial V}{\partial n}$ is less than 2.0×10^{-5}, there will be convergence due to shear. The mark) shows that divergence results from either curvature or shear, but, in general, the curvature term is much larger than the wind shear term. Therefore, 12 out of 13 cases in the Table 1 show divergence; while in the Table 2 all 7 instances indicate convergence.

Table 1. State of divergence on 500mb level during W-ly monsoon.

			Shionomisaki-Yonago		Wazima-Vladivostok		$\frac{\partial v}{\partial n}$	Yonago-Tokyo	Diver-gence	Wind at Kobe	
			Height Difference	Mean Wind	Height Difference	Mean Wind		Height Difference		Direction	Velocity
				m/s		m/s	$\times 10^{-5}$				
Jan.	12.	1953	42	45	43	17	5.0	−48	◎	WSW	14.9
Feb.	15.	〃	40	42	45	18	4.4	−9	◎	WSW	15.8
Mar.	11.	〃	23	24	49	19	0.9	−13	○	WSW	14.5
Dec.	10.	〃	50	51	47	18	6.4	−34	◎	W	16.1
Jan.	25.	1954	36	39	36	15	4.2	−8	◎	WSW	16.5
〃	28.	〃	36	39	28	11	5.0	00	◎	W	14.9
Dec.	12.	〃	19	21	16	6	2.6	−7	◎	W	14.0
Jan.	6.	1955	39	41	17	7	6.4	−14	○	W	14.0
〃	10.	〃	48	52	21	8	8.8	−22	◎	W	13.7
〃	16.	〃	29	32	33	14	3.0	+26	○	W	14.9
〃	20.	〃	52	54	33	14	7.6	−27	◎	W	17.1
〃	30.	〃	35	36	30	13	4.4	−10	◎	WSW	14.2
Feb.	20.	〃	54	56	15	6	9.9	−48	◎	WSW	19.3

Mark ◎, denotes the case both curvature and wind shear show divergence;
Mark ○, denotes the case either curvature or wind shear shows divergence;
Mark ×, denotes the case both curvature and wind shear show convergence.

Table 2. State of divergence on 500mb level during N-ly gale.

			Shionomisaki-Yonago		Wazima-Vladivostok		$\frac{\partial v}{\partial n}$	Yonago-Tokyo	Diver-gence	Wind at Kobe	
			Height difference	Mean wind	Height difference	Mean wind		Height difference		Direction	Velocity
				m/s		m/s	10^{-5}				
Jan.	3.	1953	28	30	30	11	4×10^{-5}	+13	○	N	16.6
Nov.	27.	〃	12	14	35	14	0	+5	×	NNW	16.3
Feb.	12.	1954	8	9	51	21	−2.6	+8	×	NNW	17.3
〃	21.	〃	21	24	46	18	1.0	+2	×	NNW	14.4
Mar.	13.	〃	20	22	36	15	3.0	+12	○	NNW	14.9
Feb.	28.	1955	50	53	52	21	4.4	+23	○	NNW	14.0
Mar.	4.	〃	20	23	85	30	−10.0	+6	×	N	16.8

Marks same as in Tabie 1

Outbreak of cold air

We find varied cases through the synoptic study of the cold air outbreaks during the years 1954 ~ 1956. It is, however, common to all cases that the cold air pool remains stagnant in the quarter between 50°N to 60°N and 110°E to 150°E and that its axis

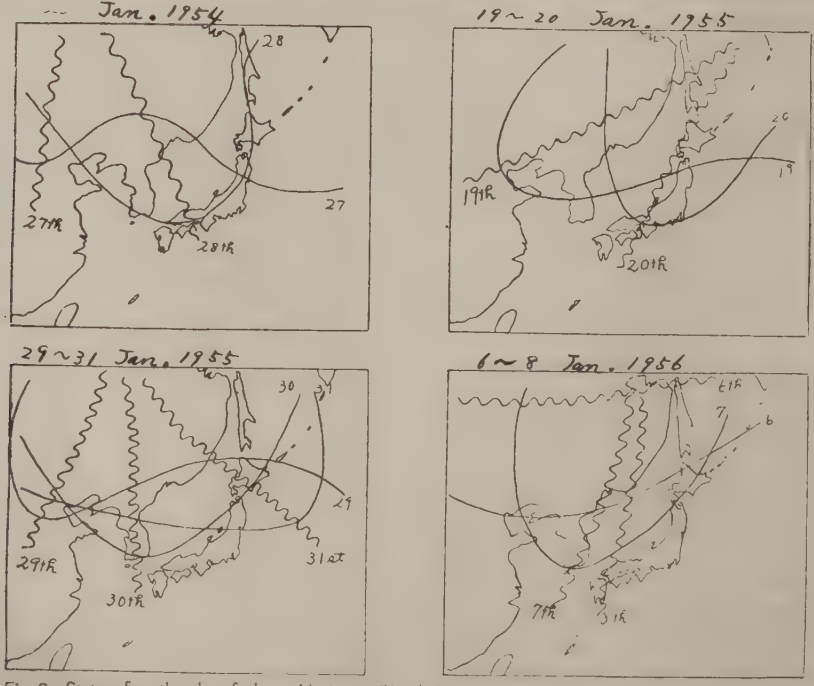

Fig 2 State of outbreaks of the cold air on 500mb level
The solid line indicates the temperature and the waved line shows the axis of the cold air.

extending southward from its center, shows a counter-clockwise movement.

Figure 2. shows the typical cases.

Ex. 1 Axis of cold air is moving E-ward, but the southern part of it shows an advance much faster than the northern part.

Ex. 2 Core of cold air lies over the Sea of Okhotsk and its axis is moving counter-clockwise.

Ex. 3 Axis of cold air is moving counter-clockwise with a point near 55°N, 120°E as the center.

Ex. 4 Similar to ex. 3; but the speed of the movement comes suddenly slow down over the western part of Japan. In this case, the duration of the monoon is longer.

Besides the above examples, there are other cases of monsoons occuring during the southward movement of the cold air core and, rarely, without any outbreak. In exceptional cases, the axis of cold air is found extending E-W without any strong outbreak.

When the axis of the cold core turns fast, the monsoon will prevail only for one day; but, when the movement of the axis is delayed around 130°E, it will last two or three days.

Long wave ridge.

The positions of the long wave ridge on the mean chart of the northern hemisphere are found respectively at 80°E to 90°E in central Siberia and at 150°W to 160°W in the Ocean to the west of the north American continent. While the long wave trough is located at 140°E to 150°E.

Two conditions are necessary for the monsoon explosion, when the cold air appears in Eastern Siberia and moves southward. First, there must be a force to drive the cold air southward, namely, the strong northwinds; in that event the ridge at 90°E has to be extremly sharp. On the other hand, we have no monsoon in western Japan when the cold air break out beyond the 140°E. Therefore, there must be some power to prevent of the cold air moving eastward across 140°E; that is to say, there must be a strong ridge around 160°E. This ridge will necessarily be accompanied by a divergence near Japan, and in consequence it serves to develop the cyclone arround the Japan Sea.

When these two ridges are simultaneously strong, we may expect the outbreak of the cold air and the resultant monsoon.

Table 3.
The ridige position of the before day when the monsoon begine.

	Position of the western ridge	Position of the Easten ridge	
		Secondary	main
Jan. 5.1955	95° E		160° E
〃 9. 〃	95° E	155° E	
〃 15. 〃	90° E		165° E
〃 19. 〃	95° E	160° E	
Feb. 8. 〃	90° E	153° E	
〃 19. 〃	90° E		167° E
Jan. 6.1956	75° E	160° E	(170°W)
〃 23. 〃	90° E		165° E
〃 27. 〃	80° E	155° E	135°W
Fec. 9. 〃	65° E		180° E
〃 28. 〃	60° E	150° E	

We have studied the examples of Monsoons for the two years 1955~1956, with regard to the position of the ridge at 50°N. The data used are those obtained from the 700mb analysis that is broadcast by the Central Meteological Observatory at Tokyo.

The results of our study are shown in Table 3. From this Table, it may be seen that there are a main ridge around 90°E and another around 160°E.

i) Eastern ridge.

As regards the ridge at 160°E, it is easy to forecast the monsoon when the ridge is strong from the begiring or is a remarkable blocking high. As clear from Table 3, the ridge forms a secondary one in many cases. In such cases, the formation of a ridge must be foreseen around 160°E. We have classified the ridge formation into those types according to the profile of a standard iso-hypses (9800 feet) on the 700mb chart.

Type A: The ridge is blocking high or a long wave one, and there is little change in the pattern.

Type B: The short wave ridge near Japan becames stronger as it moves eastward, and reaches around 160°E just when the monsoon start.

Type C: When the distance between the long wave ridges is great and exceeds 120° long., there must be a wave retrogression or a new wave formation has to occur around 160°E.

ii) Western ridge.

When a short wave ridge moving estward is superposed on a long wave ridge around 90°E, the latter will apparently move eastward and gradually grows in strength, while the radius of curvature of this ridge profile will become smaller and approach the limited value of the anticyclone radius of curvature.

Then the cold air will break out under the influence of the unbalanced atmosphere. After the outbreak of the cold air, this unbalance will rapidly disappear. The process of this change is illstrated in Fig. 4. On the 17th the ridge has a considerably large radius of curvature. As the ridge moves toward the east, the radius becomes smaller untill it comes to have the approximate limited value of about 300km

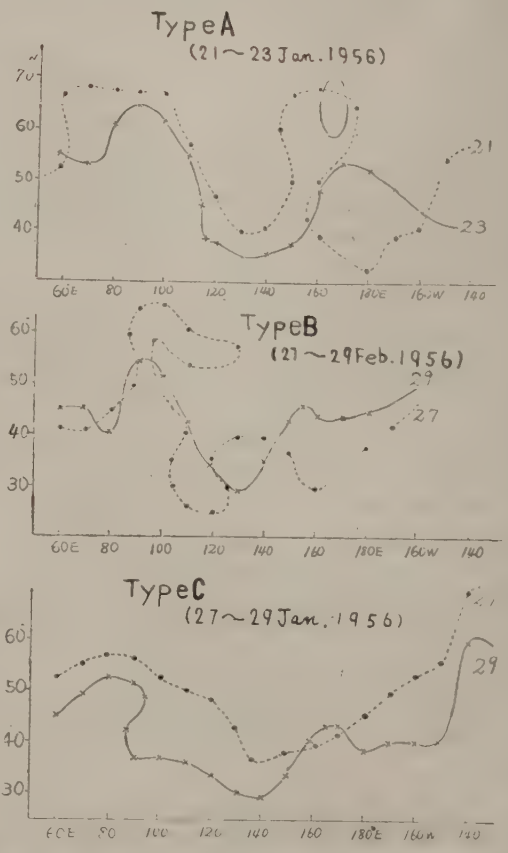

Fig 3 The height profile of today and two day ago when the monsoon begins to blow.
The actual line indicates the height profile of today and the dotted line indicats two days ago.

on the 19th, one day before the monsoon begins to blow.

Consequently, with the outbreak of cold air, the centre of the ridge moves south and at the same time the radius of curvature rapidly increases so that the atmosphere becomes stabilized again. Table 4 shows the results obtainded from 6 examples in which it was possible to calculate the radius of curvature.

From this table, it will be seen that the radius of curvature is smallest on the day before the monsoon.

Table 4 The radius of curvature on 700mb level.

Day.	−2	−1	0	+1
The radius of curvature. lat.	8.3°	4.4°	6.7°	9.1°

Mark 0 indicates the day when the monsoon begins to blow.

Mark − indicates before the day and mark + indicates after the day.

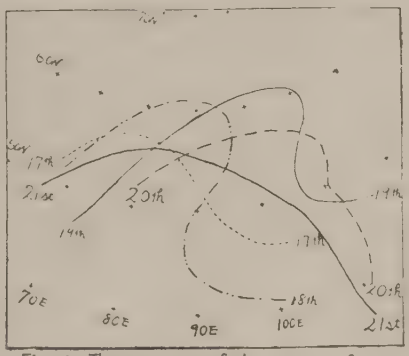

Fig. 4 The movement of the contour of 9800 feet on 500mb level during Feb. 17~21, 1955.

Vertical solenoid

In order to a trough to deepen, it is essential that there should be a strong direct solenoidal circulation in each of the northwestern and the northeastern part of it and a weak one or rather an indirect solenoidal circulation in the southeastern part of it.[3]

However, the indirect solenoidal circulation cannot actually be calculated from the chart itself. None the less, it is still possible to estimate its degree from the weather or from the development of a cyclone on the surface maps.

Let us now discuss and calculate the direct solenoidal circulation. Acording to Prof. Holmboe,[4] a formula of circulation can be obtained as follows:

$$\int_c \dot{\mathbf{V}} \cdot \delta r = -\int_c \alpha \, \delta p = -Rd \int_c T \, \delta (\ln p) \qquad (2)$$

It is easy to integrate this equation around a rectangle which is surrounded by two vertical lines and two isobars (for instance, 1000mb and 700mb):

$$\int_c \dot{\mathbf{V}} \cdot \delta r = Rd \, (T_{mB} - T_{mA}) \ln \frac{P_1}{P_2} = \varphi_B - \varphi_A$$

Here, φ indicates the thickness. Acordingly, the above equation shows that the difference of thickness between two points A and B indicates the circulating acceleration between them.

By applying this theory, we can calculate the solenoid around the trough. Fig. 5 shows one example, in which the solenoide has been calculated as of midnight, February 18, 1955. In this chart, the double solid line indicates −25°C at 700mb and the double dotted line that of midnight, February 19. It may be observed that the cold air has a remarkable outbreak and forms a strong trough on the 20th.

The actual solid line in this chart shows the solenoids as calculated on the basis of the map for the 19th. Lake Baikal in the west of the cold air and the Sea of Okhotsk in the east of it are both placed in a strong solenoidal region.

This means that the cold air in its western part moves southward with subsidence, while in the east it moves northward with upward motion.

Consequently, the cold air, first stretched east to west, may come to extend south to north as time passes by. In the while, no subsidence will result at the southern edge of the cold air because of the very small solenoid. It will be worth while here to call attention to the cloudy weather in Korea, where we can see an indirect solenoidal circulation or vertical motion.

Fig 5 Distribution of the Solenoidal circulation and change of −25°C temperature on 700mb level

Zonal current

Acording to "Dynamic Meteorology" by Holmboe and his colabolator, the following formula may be used for a curvature of an isobar on the meridian when the vorticity maintains its steady state:

$$0 = \int_c \omega_a^2 R \bullet \delta r + N\alpha, -p \qquad (4)$$

The solenoid term, $N\alpha, -p$, in (4) will endeavour to form a direct meridional circulation around the solenoid, and, as a rule, the heavy cold air in the polar region will subside and move southward, while the light warm air in the neighbourhood of the equator will move northward at the upper level.

Formula (4) indicates that this solenoidal force must balance with the centrifugal force if a stationary state is to be maintained.

This balance may be broken by the appearance of strong cold air when the upper winds are weak. As a result, the cold air will begin to move southward and the outbreak take place.

Keeping this fact in mind, we have checked the wind profile at 500mb on the chart and have found that the zonal current weakens 3 or 4 days before the outbreak of the cold air.

Fig. 6 shows one example during January, 1956. In this figure, the monsoon occured on the 7th and the 23th; and, on the 3rd and the 19th, four days ahead of the day of outbreak, the zonal winds are found to weaken.

But this weakening is not a necessary condition for the cold air explosion. For this purpose, we examined 11 occasions during 1955 and 1956. The height difference between Vladivostok and Naha on the 500mb chart had

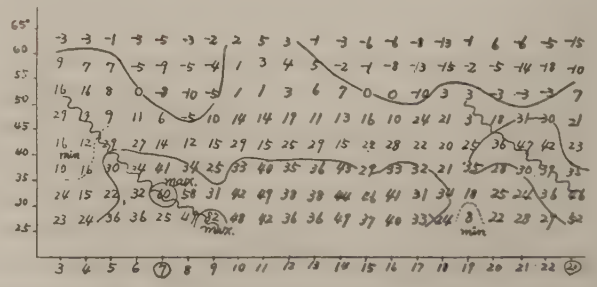

Fig 6 The Wind profile during January 1956.

been used for purposes of a simple test, and we have gained the following results: 6 out of the 11 cases satisfy the condition; in 3 the weakening happened 2 days ahead and in 2 one day ahead. Therefore, we may do well to remember this rule and may use it with some advantage in the case of forecasting the cold outbreak.

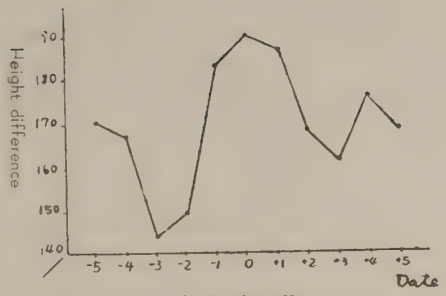

Fig. 7 Change of the height difference between Naha-Vladivostok

Fig. 7 shows an average change of zonal winds for ten-days centering on the very day of the occurrence of the monsoon. This indicates that the zonal winds weaken 2~3 days before the cold air outbreak and strengthens on the day when the monsoon begins.

According to H. Riehl, the most favourable index stage for the cold air outbreak is S II to S III. Our study about the winter of 1956 has led us to the same result. Let us show the movement of the relative maximum in Fig. 6.

Sign on the surface map

The final step in our process of forecasting the monsoon has to do with the surface maps. It has been said that the monsoon occurs when the pressure gradient between two fixed points becomes greater, but here, we have classified the surface pattern into 3 types, based on a forerunning depression and a continental anticyclone.

i) Type A

A depression along the Pacific Coast of Japan is apt to develop considerablly, when the distribution of pressure is such that it is high in the north and low in the south. When this depression moves eastward beyoned 140°E, the pattern changes gradually into a west-high and east-low one; and then, a weak depression, appearing in the western part of the Japan Sea, is apt to develop rapidly into the monsoon.

Therefore, we are enabled to forecast the monsoon outbreak 3~4 days in advance by taking notice of the forerunning depression.

This type corresponds to the weakening of the zonal current 3~4 days before the monsoon; and it may rather be said that this cyclone passing along the Pacific Coast is the cause of the weakening of the zonal current.

ii) Type B

This type has two cyclones, one in the Japan Sea and the other along the Pacific Coast.

The monsoon will occur when the cyclone along the Pacific Coast disappear or weakens and the other moves on to the sea east off the Kanto district.

The cyclone located in the Japan Sea must go beyond 140°E before the monsoon starts. This is contrary to Type A. This corresponds to the case where the minimum zonal wind appears two days ahead of a monsoon.

iii) Type C

When a continental anticyclone extending far south from the Luchoos to the sea sou-

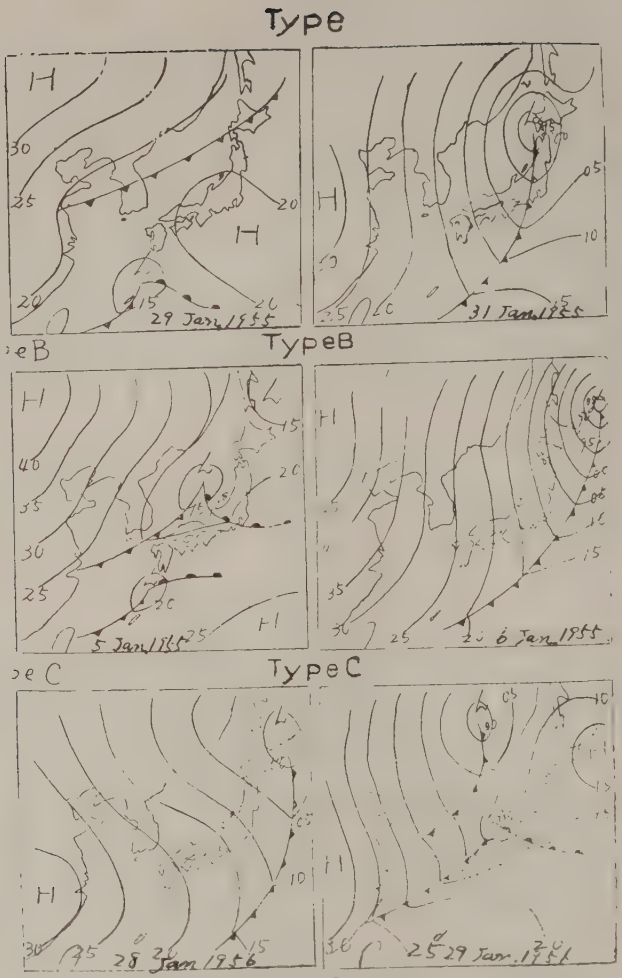

Fig. 8 Surface maps.

th of Japan constitutes a "south high" pattern at the begining, a depression forms in the Western Japan Sea and has a habit of developing into the monsoon.

This corresponds to the case where the zonal winds decreases one day before the monsoon begins to blow. This type of the monsoon can hardly be forecasetd.

Conclusion

As stated above, we divide the pressure patterns for the monsoon roughly into 3 types. To forecast the monsoon outbreak is surely difficult, but, when we judge the type from the specific,it is possible to make a forecast with a certain degree of accuracy. The procedures may be summarized as follows: -

i) Estimate the minimum of the zonal wind from the height difference between Naha and Vladivostok or from the winds profiles by means of the upper chart.

ii) Find the relative maximum of the zonal wind and notice to its southward movement.

iii) Judge the type of the monsoon by the strength and position of the long wave ridges.

iv) Notice the cold core in eastern Siberia.

v) Investigate the solenoidal circulation.

It must have a strong value in the east and west of the cold air and a low value in its southern part in the favourable case for the monsoongenesis.

vi) Finally decide the fonrecast according to type of the surface pattern.

Before closing this paper, the writer wish to express his best thanks to Mr. Kadoya, chief of the Meteorological Section, Kobe Marine Meteorological Observatory, for the benefit of our discussions on the subject.

References

① J. Bjerknes: Compendium of Meteorology.

② K. Kadoya: Journal of the Marine Meteorological Society, Vol. 21, No. 4.

③ Yi-Ping Hsieh: Journal of Meteorology. Vol. 7, No. 6.

④ J. Holmboe: Dynamic Meteorology.

⑤ H, Riehl: Forecasting in Middle Latitude.